DISCHARGE OF GRAIN CARGOES
IN THE PORT OF LONDON BY PNEUMATIC ELEVATORS.

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INTRODUCTORY.—Bucket-elevators have certain advantages for handling grain in bulk and many of these elevators are in use in the Port of London. The merits of this class of machine are before the Institution in a Paper on “Conveying and Elevating Machinery,” by Gardiner Mitchell. The present Paper deals only with the pneumatic discharge of grain from ships; and more particularly with two modern examples of floating and quayside plants in which oil-engines or motors and high-speed rotary exhausters have replaced the more usual vertical or horizontal compound steam-engines and reciprocating exhausters as the main power-plant of the installation.

Reference to the Papers in the Bibliography (page 931) will show that the invention of the Pneumatic Elevator on a commercial basis appears to be due to the late Mr. F. E. Duckham (*M*).

GENERAL PRINCIPLES OF A PNEUMATIC ELEVATOR.—Some form of power plant driving some form of air-exhausting plant, together with the necessary fuel, is enclosed in a steel pontoon or hull. On the deck of this hull, or at a suitable distance above it, is placed a grain receiver or canister to which the air-exhausting plant is connected. Suitable internally-armoured flexible and/or rigid pipes provided
[THE I.MECH.E.]

with nozzles are led from the canister to the grain in the hold of the craft to be discharged. These nozzles are kept buried in the grain, air rushes up the pipes in an endeavour to destroy the vacuum permanently maintained in the circuit, and in so doing carries the grain with it, which is deposited in the canister. By means of an automatic or mechanical air-lock of the tipper or rotary-wheel valve type, the grain is continuously discharged from the canister (without loss of vacuum therein) to some form of grain hopper situated at a suitable height above the deck, whence the grain is delivered either direct to craft or weighed out thereto through scales and chutes either in bulk or sack as may be required. The higher the proportion of grain raised to air displaced at any given vacuum, the more efficient will the machine be, and the less horse-power per ton of grain raised will be required. Such efficiencies are usually in the neighbourhood of 5 per cent or less.

ADVANTAGES FOR DISCHARGE OF GRAIN EX SHIP.—In spite of the very low order of efficiency obtained from pneumatic plants, they have many advantages for ship discharge, which will be found set out in detail in the Papers referred to in the Bibliography (page 931.) They may be here summarized as under :—

(a) No reasonable limitation as to size of ship discharged.

(b) Can work any kind of parcel and any method of stowage with special advantage in cases where different parcels are stowed superimposed in the same hold and separated from each other by "Matts" only.

(c) Simplicity and rapidity of shipping and unshipping.

(d) Absence of "Trimming" in the hold and dust thereby entailed.

(e) No damage or loss of weight to grain, but on the contrary aeration and cleaning during discharge.

(f) Use of ship's gear not required.

(g) Other cargoes can be removed from between decks whilst discharge is being effected.

(h) Work in bad weather due to minimum removal of hatches over hold.

(i) Permanent crew from numerical standpoint about the same ; but extra labour for ploughing gangs in the hold, and winch end men on the ship's deck are eliminated, as are also the heavy charges for ropes, ploughboards, and other gear.

(j) Output in tons per hour may be higher and usually is so ; the rate of discharge for all types of machine, however, depends on the rate of delivery from the scales rather than on the maximum

intake capacity of the plant, and therefore the conditions of delivery must largely affect the final rate of output.

(k) Reliability and freedom from breakdown caused by obstructions due to foreign matter in the grain or other cause.

(l) Costs of working and maintenance may be broadly regarded as being made up of engineering charges and bulk grain charges. It will be seen from the Table referred to later, which gives the engineering charges only, that the Pneumatic Elevator compares favourably in this respect—except in the matter of capital cost.

The general tendency of modern docks is to install pneumatic machines for floating discharge ex Ship.

TABULAR STATEMENT OF LEADING FEATURES.—The leading features of the various floating pneumatic plant working in the London docks are set out in Table 1 (pages 920–921).

It will be seen from the Table that these machines may be grouped as under :—

GROUP A.—This Group comprises the machines first constructed in which the hull is of rectangular box section; the power-plant marine boilers, together with vertical or horizontal steam-engines and horizontal reciprocating exhausters coupled thereto, either through gearing or direct; the superstructure either one or two towers, in which the grain canister and pipe-lines are superimposed over the grain-hopper, giving discharge to craft through scales and chutes; and the working position of the elevator “side on” to the ship under discharge.

GROUP B.—This includes machines subsequently constructed or converted, in which the hull power and air-exhausting plant are similar to Group A, but in which the superstructure consists of a single grain-canister and pipe-line placed on the forward end of the pontoon; the grain is re-elevated therefrom by bucket-elevator to the grain-hopper and weigh-house on the after end of the pontoon, whence maximum discharge can be effected to craft on either side of the elevator or any desired proportion thereof to craft on both sides of the elevator; and the working position of the elevator may be either “side-on” or “end-on” to the ship under discharge, the pipe-line being slewable for this purpose.

GROUP C.—This Group comprises the machines most recently constructed to the requirements of the Port Authority and the designs of their Chief Engineer, assisted by the late Mr. A. H. Mitchell (*M.*), the special features of which are briefly dealt with hereafter. In designing these machines for use in London docks the following were the main requirements.

TABLE 1.—*Particulars*

Name, Displacement in Tons. When Built.	Engine.	Power Plant. Pumps.	Drive to Pumps.	Pump Constant.*	Grain Canisters.		Cyclones or Stive Rooms. Capacity in Cu. Ft. †
					No. of	Capacity in Cu. Ft. ‡	
"Rapid." 1,000. 1905.	Steam. Horizontal Com- pound Surface Condensing. Stroke 48". H.P. 28" } DA L.P. 54" } Cyls.	4 DA Hori- zontal Pumps. Bore 4' 1". Stroke 4' 0"	Tail-Rods from Pistons.	420	2	1,700	2,000
"Mark Lane No. 2." 520. 1897.	As above. Stroke 48". H.P. 22" } DA L.P. 42" } Cyls.	2 Pumps as above. Bore 4' 0". Stroke 4' 0"	Tail-Rods from Pistons.	200	1	1,800	3,300
"Mark Lane No. 3." 880. 1902.	As above, but Vertical. Stroke 80". H.P. 19" } DA L.P. 38" } Cyls.	4 Pumps as above. Bore 4' 0". Stroke 5' 0"	3 to 1 Gear reduction from Engine.	500	2	460 †	2,500
"Chicago." 610. 1898. Reconstructed 1911.	As above. Horizontal. Stroke 48". H.P. 22" } DA L.P. 42" } Cyls.	2 Pumps as above. Bore 4' 6". Stroke 4' 0"	Tail-Rods from Pistons.	254	1	520	330
"New York." 650. 1902.	As above. Stroke 48". H.P. 22" } DA L.P. 49" } Cyls.	2 Pumps as above. Bore 4' 8". Stroke 4' 0".	Tail-Rods from Pistons.	272	1	2,000	1,200
"Turbos 1 and 2." 350. 1916.	Oil. 4-Cylinder Vertical Semi-Diesel. 200 B.H.P. 250 r.p.m.	4-Stage Rotary Exhauster. 8,000 cu. ft. Air per min. at 9" Hg. at 2,700 r.p.m.	Oil-cooled double helical speed increas- ing gear. Ratio 10 to 1.	—	1	150	600
"Dolphins Millwall." 4 Towers. 1921. §	DC Motor. 200 E.H.P. at 540 r.p.m. Voltage 460.	3-Stage Rotary Exhauster. 6,000 cu. ft. Air per min. at 11" Hg. at 3,500 r.p.m.	Oil-cooled double helical speed increas- ing gear. Ratio 8½ to 1.	—	1	2,000	200

* The "Pump Constant" gives the volume of air per revolution displaced by the total therefrom. † Shortly to be replaced by Avery Automatic Scales at 250 lb. ‡ Has

particulars given are for one tower only. The date 1921 is for reconstruction. Plant was Horizontal Drag is that length of horizontal or partially horizontal pipe-line which is Vertical Lift is that length of vertical piping which has normally to be added to the

of Machines.

Grain Intake Pipes.					Weigh-House.			Remarks.		
No. of.	Dia. in In.	Horizontal Drag.	Vertical Lift.	Type of Nozzle.	No. and Type of Scales and how placed.	Height from Floor to Water Level.	Dia. of Discharge Chutes.	For Wheat Discharge.		Group Letter.
								Normal Engine Speed.	Normal Vacuum In. Hg.	
8. Four per Canister.	6	30' of 6" parallel.	70' of 6" parallel.	6" Bent.	14 Avery Autos at 250 lb. 7 each house, one side only.	18' 6"	7" sq.	50	7"	A.
4	6	30' tapers 10" to 6".	70' of 6" parallel.	6" Straight.	10 Hand Lever. 5 each side of House.†	12' 3"	7" sq.	40	8"	A.
4. Two per Canister.	7	34' tapers 12" to 8".	70' tapers 8" to 7".	7" Bent.	12 Hand Lever. 6 each house, one side only.†	13' 9"	6" sq.	70	10"	A.
2	7	40' tapers 15" to 12".	50' tapers 12" to 7".	7" Bent.	6 Avery Autos at 250 lb. placed centrally.	24' 0"	6½" round.	36	10"	B.
4	6	30' tapers 15" to 8".	50' tapers 8" to 6".	6" Bent.	8 Avery Autos at 250 lb. 4 each side of House.	15' 0"	9" sq.	40	9"	B.
2	8	45' tapers 18" to 12".	40' tapers 12" to 8".	8" Bent.	6 Avery Autos at 250 lb. placed centrally.	23' 4"	8" round.	Exhauster Speed 2,400	7"	C.
2	7	30' tapers 10" to 7".	50' of 7" parallel.	7" Taper.	10 Hand Lever. All on one side between Dolphin and Quay.†	27' 0"	6" round.	Exhauster Speed 3,250	10"	—

number of Pumps fitted. Clearances and tail-rods, areas, etc., have not been deducted been reduced to size given by internal baffling. § All four towers are similar; the built in 1903. || Approximate only from over-all dimensions. carried permanently attached to the canister. permanent vertical pipe-line carried in order to work a ship.

The Hull should be as small in dimensions and draft as conditions of stability permit; should be manoeuvred about any dock by power-winch and rope; and should tow from dock to dock in safety.

The Power-Plant should give a minimum of maintenance and stand-by charges for intermittent working of machines.

Superstructure.—To discharge wheat in bulk *ex* ship at the rate of 100 tons per hour in either the “side-on” or “end-on” positions and is to be so arranged that :—

- (i) There is the necessary margin of stability for the vessel.
- (ii) The pipe-lines can be shipped, unshipped, and manoeuvred in the hold with rapidity.
- (iii) That the length and disposal of the permanent portion of the pipe-line attached to the elevator shall be such that the supplemental labour charges for the *addition* of further pipe-line are a minimum.

The method of effecting these requirements is hereafter briefly described.

DETAILS OF DESIGN OF PLANT : GROUP “C.”

The Hull.—Reduced to 60 ft. long by 30 ft. wide at deck level, depth 11 ft. 6 in. and about 6 ft. 8 in. loaded draft—sides of pontoon raked and made swim-ended fore and aft, and provided with budget plates for ease of towing.

The Engine.—The obvious disadvantages of a steam-plant for intermittent working are the space occupied by, maintenance of, and attendance on the multitubular marine-type boiler—whether the machine be working grain or idle; and the cost of loading, stowing and handling the coal therefor.

A 200-h.p. four-cylinder vertical semi-Diesel oil engine made by Messrs. Vickers Petters was fitted, and is of their standard VJ 4 type. Normal running speed is 250 r.p.m., but an auxiliary hand-operated governor is provided to enable the engineer to vary this within limits for the different classes of grain to be worked. Fuel is Anglo-American or other approved gas-oil of a specific gravity of about 0.86 and flash-point of 150° F.; fuel consumption is $\frac{1}{2}$ pint per b.h.p.-hour, and about 3,000 gallons is carried in two cylindrical tanks disposed inside and one on each side of the pontoon. Starting up is by compressed air, blow lamp, ignition tube, etc., and can be effected in less than three minutes from cold. A large fly-wheel is fitted to minimize cyclical variation. Cooling is by circulation of dock water to engine-jackets; there is no water injection to cylinders. The engine exhausts are carried about 30 ft. above deck level and are

provided with silencers, water sprays, etc., also hand-holes to facilitate periodical cleaning.

The Air-Exhausting Plant.—On account of the large volume of air to be dealt with at low pressure, any type of reciprocating exhauster, whether horizontal or vertical, must be fitted with a number of inlet and exhaust valves of large area; or a greater number of valves of small area. The Port Authority has no plant to date fitted with vertical reciprocating exhausters; but there is no doubt that the maintenance of these valves is a big item for the horizontal type. Dust gets between the valves and their leather, rubber or other form of seating; which is rapidly eaten away with a consequent drop in efficiency, and stoppage of the plant for renewals; this also applies to the cylinders themselves with the piston and/or junk rings therein. For these and other reasons it was decided to abandon reciprocating and fit rotary exhausters. The exhauster fitted is of the "Rateau" pattern, four-stage single flow made by Messrs. Fraser and Chalmers of Erith, and was designed to be capable of dealing with a quantity of free air equivalent to 8,500 cu. ft. per minute maintained at a vacuum of 9 in. of mercury below atmospheric pressure at a temperature of 60° F., when running at 2,700 r.p.m. Forced lubrication is provided for all main bearings. The joint in the casing is horizontal, and tackles, etc., are fitted to facilitate inspection of the rotor-impellers. The exhaust is carried about 30 ft. above deck level, is placed remote from the engine exhaust, and is provided with a form of flap-valve to eliminate any effects of back pressure due to surging. No maintenance or other charges have been incurred with this portion of the plant, which has been at work since 1916; and, due to the large and efficient dust cyclone fitted, no appreciable wear is visible on the rotor impellers.

The oil-engine is connected to the exhauster by double helical oil-cooled gears made by Messrs. David Brown of Huddersfield. The ratio of speed increase is about 10 to 1. Flexible couplings made by Messrs. Wellman Bibby Co., Ltd., of London, are interposed between the oil-engine and the gears, and the gears and the exhauster. The reduction on the cost of running the elevator as a whole effected by fitting the above described type of main power-plant may be seen from the Tables of Cost referred to later.

Design of Superstructure.—The general lay-out of this portion of the plant can be seen from a drawing* which has been published in the technical press, and was built by Messrs. Henry

* *The Engineer*, 28 Feb. 1919.

Simon, Ltd., of Manchester. The pipe-crane and pipe-line is arranged for slewing for either "side-on" or "end-on" working; also for luffing for rapidity in getting in and out of a ship's hold and for variations in the beam and freeboard thereof. The principle of the auxiliary elevator from grain canister to grain hopper is retained in order to ensure stability on the relatively small hull. The whole of the pipe-boom complete is carried attached to the elevator and is provided with permanent vertical telescopic portions to minimize the length of additional pipe required to work a ship, and the supplemental labour charges incidental thereto as previously referred to. The operation of the pipe lines and extra lengths of pipe is effected by motor-driven winches, etc., attached to the pipe-crane and is controlled from a driver's cabin thereon. These motors are supplied from an auxiliary generating set of the oil-engine cum dynamo type. This auxiliary set also supplies power for the bucket-elevator motor, the grain tipper, the dust cyclone wheel valve and worm, the deck capstan, the air-compressor, bilge pump and fan, fuel pump, etc., and for the lighting throughout the vessel.

CONVERSION OF POWER-PLANT AT MILLWALL DOCKS.—A full description of the arrangement of the pneumatic intake plant at the Dolphins central granary, Millwall Docks, prior to conversion, will be found in the Papers referred to in the Bibliography. Briefly, it consisted of a wooden staging or dolphin standing at about 50 ft. from the central granary quay; and being about 350 ft. long, 25 ft. wide and 14 ft. above Trinity high-water level. The superstructure on the deck of this dolphin consists of four pneumatic grain-handling towers of the Group A type, complete with necessary grain-pipes, hand-lever scales, etc. This superstructure has been or is only to be altered in two respects:—

(a) Dust cyclones, wheel-valves and worm-conveyors of Group C type have been added for the better protection of the rotary exhausters to be described hereafter.

(b) The hand-lever scales are being replaced by Avery automatic scales.

The power-plant consisted of boilers, steam-engines and horizontal reciprocating exhausters of the Group A type, housed beneath the deck of the dolphin, and it is the whole of this plant which has been replaced by four sets of Group C type power-plant operated by electric motors instead of oil-engines. The four sets (one per grain-tower) are arranged in pairs, each pair being enclosed in an engine-house standing upon the deck of the dolphin; it has therefore been possible to complete the erection of the new plant

FIG. 18.—*Dolphin Grain Elevator, Millwall Docks.*

before discarding the old, thereby keeping the plant in commission throughout. The general lay-out of the new plant is shown in Fig. 18; each of the four sets is identical, and a brief description of one set is given below.

Motor-driven Rotary Exhauster Sets.—These were constructed by Messrs. Reavell, of Ipswich. Each set consists of a motor with necessary starter, etc., connected through flexible coupling to oil-cooled speed-increasing gear, which is again connected through flexible coupling to a high-speed rotary exhauster; the whole of the unit is carried on one common bed-plate.

The Motor is of the open protected type, compound wound and fitted with interpoles. To work on D.C. Current at 460 volts pressure; shunt regulation of speed from about 360 r.p.m. to 600 r.p.m. Horse-power, 200.

Speed-increasing Gear.—Both flexible couplings are of the pin and rubber bush type. The gear is of the double helical type and is oil-cooled, the oil being circulated to gears and bearing by pump-driven through worm-gear off the main low-speed shaft, a magnetic oil-strainer and cooler being provided. The oil pressure is between 6 and 10 lb. per square inch and a gauge and relief valves are fitted. Water for the oil-cooler is provided by a small rotary pump driven by belt from the low-speed coupling. The ratio of speed increase is about $6\frac{1}{2}$ to 1 and a tachometer is fitted.

The Exhauster.—The rotor consists of three impellers mounted on a rigid shaft revolving in roller-bearings; there is a thrust-bearing and two main roller-bearings which are supplied by the gear-case oiling system and return their oil to the common sump. Attenuated air is led from the cyclone to the exhauster inlet and is discharged at or slightly above atmospheric pressure on the outlet, a butterfly valve being fitted in the inlet or suction opening. The suction side is connected to a 30-in. mercury gauge and an automatic dial type vacuum recorder; and the delivery side is connected to a 30-in. water-gauge. The duty of the exhauster is to aspire 6,000 cu. ft. of attenuated air at a pressure of 11 in. of vacuum (Hg) and to compress this to atmospheric pressure for delivery. These conditions are fulfilled when the motor speed is about 540 r.p.m. and the exhauster speed about 3,500 r.p.m. If the motor speed be raised to 600 r.p.m., the exhauster speed becomes 3,900 r.p.m., and a maximum vacuum of 14 in. Hg. may be obtained.

Switch-Gear.—Elaborate switch-gear is fitted with the object of preventing the motor being subjected to heavy overloads either during starting up or under running conditions. This switch-gear is not vital to the plant and will not here be described.

OPERATION OF PLANT.—The conversion has only been effected for a few weeks, but during this period the plant has run well. For this reason it has not been possible to include any figures for the plant under Table 2 (pages 928–929); it is, however, certain that the engineering charges will be appreciably reduced. The Author hopes to obtain test data for this conversion prior to the discussion of this Paper.

ENGINEERING AND BULK GRAIN COSTS.—Cost for the floating pneumatic elevators apart from establishment and other special charges may be regarded as being made up of engineering and bulk grain costs. Engineering costs refer to the working and maintenance of the machines themselves and the engine-room crew therefor, and will be found set out in Table 2. Bulk grain charges are for extra labour employed on or about the machines in connexion with the actual discharge of grain, and include such items as wages for grain superintendents and their staffs, foremen, shipworkers, deck crews, gangs in the ship's hold and aboard the elevator itself, weighers for operating the scales, etc.

From the Table it will be noted that the Group C or new machines show to advantage in the matter of engineering costs.

TEST RESULTS AND REMARKS THEREON.—Certain “chute loose” tests on Group C machines are set out in the Table of Tests. In considering these results, it should be noted that they are not a measure of the maximum rate at which the intake or pneumatic portion of the machine would lift grain; but only of the limited rate at which weighers deliver it to craft; and further that any delays caused by faulty operation of the grain-pipes in the ship's hold, or the craft receiving delivery are included therein. The rates of discharge given in the Table of Costs have been reproduced in Table 3 (page 930) to show that these and similar delays have a very appreciable effect on the performance of the machine.

CONCLUSION.—It has not been possible to refer to the operation of the plant as a whole and more particularly the rotary exhauster portion thereof when actually working grain; this matter will no doubt arise in any discussion which there may be on the Paper. The Author wishes to record his thanks to Mr. C. R. S. Kirkpatrick, Chief Engineer to the Port of London Authority, for permission to publish the figures given; and to General Mowat, the Institution's Secretary, for assistance in the preparation of the Paper.

The Paper is illustrated by 1 Fig.

TABLE 2.—*Costs of Working*

Name and Group.	Working.		Fuel Consumption.				
	Tons.	Hours.	Tons per Hour.	Elec- tricity. Units.	Oil. Gall.	Coal. Tons.	Tons Grain per Unit.
" Rapid " A.	88,174	1,183	75	—	—	950	—
" Mark Lane 2 " A.	60,468	1,027	59	—	—	460	—
" Mark Lane 3 " A.	76,734	1,424	54	—	—	620	—
" Chicago " B.	72,292	1,179	61	—	—	601	—
" New York " B.	56,683	870	65	—	—	446	—
" Turbo 1 " C.	69,154	1,214	57	—	11,902	—	—
Bucket-Elevator " Mitchell." }	47,046	768	61	—	—	30§	—
Bucket-Elevator. Nos. 1 to 8 Elevators and 2 Steam Barges }	111,911	2,215	51	—	—	258	—
Bucket-Elevators A B C D. }	76,616	1,444	53	29,740	—	—	2.58

* The above are engineering division working costs only,

† Deductions as shown in " Remarks " column ; being cost
be made in order to arrive at a normal total cost per

‡ It will be noted that generally speaking wherever the cost

§ To nearest ton.

*of Machines. Year 1919-20.**

Fuel Consumption.		Costs in pence per Ton of Grain.			Total Cost (pence) per Ton of Grain raised.†	Remarks.
Tons Grain per Gal.	Tons Grain per Ton.	Wages.	Fuel and Stores.	Maintenance.		
—	93	4·27	5·68	3·22	13·17	Steam. Two Tower Machine.
—	131	4·33	3·82	4·33*	12·48	{ Steam. Single Tower Machine. Deduct 1 penny per ton from maintenance for unusually large Boiler repairs.*
—	123	3·82	3·54	1·48*	8·84	{ Steam. Two Tower Machine. Cost of maintenance unusually low as Machine only had 3 overhauls in year instead of 4.*
—	120	4·03	4·41	2·27	10·71	Steam. Single Tower Machine.
—	127	5·56‡	3·80	3·47	12·83	Steam. Single Tower Machine.
5·8	—	3·09	2·37	1·44	6·90	Oil. Single Tower Machine.
—	1,585	3·33	0·55	2·96	6·84	{ Bucket-Elevator. Slewing and luffing Cantilever type. Suction Gas.
—	436	5·97	1·67	5·62	13·26	{ Steam. Elevators and Conveyors hand rigged.
—	—	3·76	0·69	5·05	9·50	{ Motors. Elevators and Conveyors hand rigged.

exclusive of general charges, interest and depreciation.

per ton of abnormal or unusual charges on ordinary maintenance; should ton for the year.

in pence per ton for *Wages* is high the tonnage handled for the year is low.

TABLE 3.—Average Test Results for Group C Machines.

Machine.	Length of Pipe-line in Feet.	Quarters of Grain.†	Net Time in Hours.	Main Engine. Fuel consumed in Pints.	Quarters per Hour.	Tons of Grain per Hour.*§	Pints of Fuel per Hour.	Pints 1.6 = B.H.P.†	B.H.P. per Ton per Hour.	Average. Results for Ten Tests on <i>each</i> Machine in 11 different Ships.¶
Turbo 1	72	2,569	8	584	321	71	73	122	1.72	Engine Speed, 250 r.p.m. Vacuum, 7".
	85	2,933	9	720	326	72	80	133	1.85	Quarters of Grain per Hour, 304. Tons per Hour, 67.
	90	1,179	3 $\frac{3}{4}$	270	314	70	72	120	1.72	Pints of Fuel per Hour, 76. Length of Pipe-line, 83'.
	90	1,709	6 $\frac{1}{2}$	487	263	58	75	125	2.16	B.H.P. = 127. B.H.P. per Ton per Hour = 1.9.
Turbo 2	70	2,767	7	483	395	87	69	115	1.35	Engine Speed, 250 r.p.m. Vacuum, 7".
	80	3,000	9	634	333	74	70 $\frac{1}{2}$	117	1.59	Quarters of Grain per Hour, 325. Tons per Hour, 72.
	90	1,532	5	370	306	68	74	123	1.81	Pints of Fuel per Hour, 73. Length of Pipe-line, 83'.
	104	1,383	5 $\frac{1}{2}$	423	251	56	77	123	2.28	B.H.P. = 121. B.H.P. per Ton per Hour = 1.68.

Dolphins Millwall. Cost and Test data, if available, will be given during Discussion of Paper.

* Wheat assumed at 4.52 quarters per ton.

† All results are for Wheat discharge as weighed out *through* Scales.

‡ Fuel consumption assumed at 0.6 pint per b.h.p.-hour.

§ Tons per hour from Table 2 = 57.

¶ Average for the two machines over the twenty Tests = 1.73 b.h.p. per ton of Grain per hour.

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Discussion in London, on Friday, 16th December, 1921.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to the Authors for their Papers.

Mr. C. R. S. KIRKPATRICK (Chief Engineer, Port of London Authority) referred briefly to Mr. Mitchell's Paper. In the Port of London, the conveyer plant could be used for discharging almost every class of goods which had to be discharged. At the present time it was used chiefly for hung beef, mutton, grain, case goods, tea, and all sorts of other things. He regretted that Mr. Mitchell had not told them how to convey or to sort timber mechanically. In timber there was a great problem to solve. It had puzzled him now for all the time he had been at the Port, and he had never found anybody yet who had succeeded in solving it. A ship arrived loaded full of deals. These were unloaded by the derricks on board ship on to the quay, where they lay all higgledy-piggledy. All the multitudinous signs and marks had then to be sorted out, and conveyed by hand to the piling-stacks. He was looking out for a genius who would be able to overcome this difficulty.

Dealing with Mr. Knight's Paper, as it referred to work in London it was of particular interest to him, and he would like to congratulate the Author on it. He was glad to see that Mr. Knight had gone to the trouble of putting together figures, which were always of value, so that somebody else might improve upon them. He regarded the late Mr. Duckham as the pioneer of the pneumatic process of grain discharging. The work that gentleman had done was invaluable, and it had rather gone to his (Mr. Kirkpatrick's) heart during the last eighteen months to have had to pull out what Mr. Duckham had done and put in something else in its place. But he had consoled himself with the thought that Mr. Duckham had done the spade work, and that they were out now to try and improve upon what he had invented.

At Millwall Docks there were very heavy horizontal reciprocating engines with air-exhausters and steam-boilers. Those had had to be replaced, and he (Mr. Kirkpatrick) came to the conclusion that the best thing to do was to install turbo-exhausters. He found that the old steam-plant which had been put down by Mr. Duckham occupied, with the engines and boilers, 60,000 cu. ft. The new electrical plant with the turbo-exhausters took up 22,000 cu. ft. The weight of the old steam-machinery was 163 tons, and the weight of the electrical machinery by comparison was 50 tons. Therefore it would be seen that, in a confined space, such as the jetty at the Millwall Docks, there was, from that point of view alone, a considerable advantage in the use of turbo-exhausters.

It was perhaps fitting that he should say something on how those turbo-exhausters first came to be tried. Second to Mr. Duckham, he regarded the late Mr. A. H. Mitchell as being the pioneer. Mr. Mitchell had been with the Port of London Authority for many years, and his inventions were invaluable; in fact, his whole life and soul had been wrapped up in the improvement of the pneumatic process. In 1912 or 1913 Mr. Mitchell and he were commissioned by the Port Authority to ascertain what was being done at all the grain ports in Europe. They went right through Holland, Germany, Switzerland, and Italy, and had gained a great deal of interesting information. They had very useful discussions with Mr. Klocke, who was then the German manager of the Hamburg grain elevator plant. That gentleman had told him that his company had tried turbo-exhausters, and added that if the Port of London also tried them they would fail in the same way. However, they determined that they would try turbo-exhausters, and, although they had not brought them up to perfection, they believed they had gone a long way towards it.

In the course of that tour, he thought the most interesting thing they had seen was the plant at Genoa. If he remembered rightly, the pumps were of the vertical reciprocating type, but the general lay-out was very extraordinary. There was a jetty running out from the warehouse for two or three ships' lengths. At that jetty they had pneumatic pipes, which could be placed in the holds of ships on either side of the jetty and a long horizontal pipe leading to the warehouse. The engineer-in-charge gave them data and facilities, but told him (Mr. Kirkpatrick) that he had 1,800 h.p. and was only able to discharge 450 tons per hour. The reason was quite easy to see. The engineer discharged the grain all right and got it down on to the quay, but it had then to be dragged 1,500 feet along a horizontal pipe to the warehouse at the extreme end of the jetty. That had been a lesson to him (Mr. Kirkpatrick) to avoid the horizontal pipe. At the time when Mr. Mitchell and himself had been discussing those matters with Mr. Klocke of Hamburg, there had been a friendly rivalry going on. First one succeeded and then the other, and so on. They exchanged their ideas, and they had proposed to give Mr. Klocke the results of their experiments in turbo-exhausters in due course, but for the interruption of the War.

The problem of pneumatic discharging in London was a very difficult one, but the same problem arose with regard to bucket-elevators. The problem in Germany was very different as compared with that in this country. What they did at the German ports and at Antwerp and Rotterdam was to discharge the whole ship's cargo into barges up to 3,500 tons capacity, and the grain was taken away inland for 1,000 miles or so. In London the grain came in a great number of small parcels, and it had to be loaded into very small barges. Their barges therefore had to be continually changed, which, of course, made the discharging much more difficult and consequently more expensive than in places such as Antwerp and Rotterdam. He had been at the latter port two months previously, investigating that particular point. There had been an idea in London that they might put down much larger floating elevators and discharge much quicker, and therefore much cheaper, than was being done at the present time with the smaller machines; but he had come back from his visit with the same opinion he had formed before he had gone out, namely, that for London they had to have the elevators as small as possible, and not endeavour to turn the stuff out at such a huge pace as they did in Germany.

As a result of his latest visit to Antwerp and Rotterdam, he was leaving it open in asking tenders for new elevators, which the Port of London Authority proposed to purchase very shortly, as to

whether there should be reciprocating engines or turbo-exhausters. It might be said that that was a very weak thing to do, and that it meant to say that the Port Authority was not certain which was the right thing to use. That was exactly the position. He had not made up his mind definitely whether the reciprocating plant or the turbo-exhausters were going to stay. With the turbo-exhauster there was a difficulty with the gears which would have to be surmounted. If a direct drive could be employed and the gears done away with, the problem would be solved at once. Personally, he preferred turbo-exhausters; but what one had to be so careful about was that it was no use having the latest invention if every now and again trouble arose. He wanted something that was going to be at work day in and day out.

In conclusion, he desired to couple with the name of Mr. Duckham the name of the Institution's Secretary, Brig.-General Mowat, who had taken a very large part in the development of pneumatic elevators as the successor of the late Mr. Duckham at the Millwall Docks.

Mr. CLAUDE SCRUTTON said the subject was one in which he was very much interested. His firm handled a considerable quantity of general cargoes, and they had not got very much beyond the methods employed thirty years ago. The Papers which had been read referred to the handling of grain. There was a great difference between the methods by which grain was discharged at the present time and the way in which it had been discharged twenty years ago. But, with regard to discharging general cargo, they were in the same position as they had been for a long time past. The real difficulty was that the handling was not altogether in one section. There were so many people involved that it was quite impossible to improvise elevators and conveyors for the discharge of cargo from vessels. The whole thing had to be synchronized to the final point of delivery.

The present methods consisted of the crane and the derrick discharging the cargo on the quay, and then conveying it from the quay into the sheds by hand-truck. The crane and the derrick had become gradually less efficient year by year. The few experiments which his firm had made consisted in bringing the belting up to the ship's hatch and using the centre of the shed as the distributing point. The net result was that one could get an output something like 3 to 1 over the derrick or the crane; but it was very difficult to continue experiments if they had to be carried out, as they had to be, in a more or less disjointed fashion. Mr. A discharged; the

consumer, Mr. B, was on the quay, and Mr. C was the owner of the whole property. There was no physical difficulty in carrying out the problem, and the results were quite remarkable when one could have the necessary gear. Something would have to be done shortly in order to meet the labour conditions alone.

The second experiment his firm had made had been in dealing with what he might call box cargoes. Millions of packages of tea and canned produce came in every week. It was a very large trade, and there was no doubt there was considerable use for an elevator at once. The boxes were very easy to handle, and the elevator dealt naturally with things of that sort.

He would like to draw attention to the possibilities of doing away with the ordinary stacking on the quay. If anybody went through the sheds at the London Docks they would see them piled 15 feet high with boxes, all of which packing had to be done by hand. It was very expensive, and the time was ripe for special warehouses to deal with that class of trade. There was no reason whatever why the cargo should be handled at all. If inclined run-ways were to be built, such as they had in America, and the boxes stacked up naturally, they would simply form their own bank, and require no attention whatever from manual labour. The first question was, how much would have to be handled during the next five or ten years, and what plant was it worth putting down. The actual cost when it was down was infinitesimal. His firm would be pleased to furnish data to any Member as far as the actual experiments they had performed were concerned. It was a most interesting question, and one which he certainly thought should be taken up.

At this point the President left the Chair, which was taken by Dr. H. S. HELE-SHAW, F.R.S. (Vice-President).

Brigadier-General MAGNUS MOWAT, C.B.E. (Secretary), said that, as a former Dock Engineer, he was interested in the comparative merits of the two grain elevators, which had been put before the Meeting by Mr. Mitchell and Mr. Knight. To determine on the point one had to review, really, what was the class of grain and what were the trade conditions of the port in which the cargoes were discharged. If, as in the west of England the practice of the port permitted the grading of grain and storage in silos and large granaries and it was customary to sell the grain by grade and not by parcel, then he would say that there could be but little doubt that the ordinary bucket-elevator was the more economical method for use in bulk cargoes, where a continuous feed was obtainable.

Turning to a port such as London, where, before the formation of the Port Authority, there were three competing dock companies, a ship, on entering the Thames, was met at Gravesend by representatives of the different companies, and it was just a matter of how one could induce the vessel to come in, so as to get the better of one's competitors, and new plant, which did not comply with the established trade ideas was not likely to be remunerative. The grain which came into London from the Baltic, Black Sea, and other eastern ports was a softer cereal than that unshipped in the western ports, which traded usually with America. The former cargoes were divided by bamboo matting into numerous parcels. It was impossible to work bucket-elevators under these limitations, and the only alternative to the old method of bushelling and using the ship's gear to get the grain up was the pneumatic process. He remembered when Mr. Duckham started his first experiments how much they had been resented by the grain-workers at the docks. The method had been described as "The Devil at the docks," but they had now got used to it, and regarded it as a labour-aiding rather than a labour-saving device, and they found it much more convenient to stand by, as would have been seen by the photographs which had been thrown on the screen, just guiding the "elephant's trunks" as required, instead of having to perform laborious duties.

The speaker alluded to the considerations which had influenced the design of the Millwall dolphin plant in 1902. At that time the supply of electric current in Poplar was neither abundant nor cheap, and though the Dock Co. had considered the feasibility of putting in electric motors, which had many advantages, the question of the reduction gear had not been solved, and internal-combustion engines not being available they decided to use steam-plant which had proved effective in former instances. He (General Mowat) hoped that Mr. Knight would be able to show some alternative figures of the records of the apparatus as now remodelled for comparison with those of the system installed by the late Dock Co.

Of the improvements referred to by Mr. Knight, one related to reverting to the use of automatic ton-weighting machines. When the dolphin was designed, Avery ton-automatic machines had been put down, and these operated with great accuracy. So much contention had arisen between the shipper and the merchant with regard to the results that the Dock Co. had been compelled to take out these machines, on a question of "draftage," as the merchants contended that they were entitled to the gain of 2 to 4 lb. per ton on the turn of the scale of the sack hand-weighting machines, which were in common use at the docks. The Dock Co. had

endeavoured to make terms with them and to make up the weight in other ways, but it had been of no use, and very reluctantly they had had to take out these automatic machines and put back the four-bushel hand-weighing machines. Millwall Dock Co. might be thought to have been very conservative and backward in resorting to such methods, but they had been forced to do so by the traders for whom they catered. No doubt now that the Port Authority had the control of such things in their own hands, they were able to arrange matters so as to use appliances of such a form as those that were being re-installed.

There was another point arising out of Mr. Mitchell's Paper, and that was with regard to timber transporters. At Millwall there was a timber transporter erected from material supplied by Messrs. Bolinders of Stockholm, which took up the deals from barges. The deals had been lifted up by a hook elevator and tipped into a trough at the top, through which they were conveyed by cast-iron rollers, actuated by shaft-gearing worked by electric motors. He was sorry to say that that apparatus had not been much in favour with the traffic department or with the timber porters. It took the deals to the destination all right—it conveyed them over two public roads, over a railway, and into a field beyond. It discharged the deals in the order in which they came, but it did not sort them out, and the Dock Co. found the apparatus did not pay, because so much had to be paid to the men for sorting at the delivery end. What they wanted was something which would sort out mechanically the deals according to their respective marks. However, he thought that possibly in view of the high price of labour at the present time, the apparatus might be given another trial.

Mr. H. J. DEANE said he had known both Mr. Knight and the late Mr. A. H. Mitchell for a considerable time, and they had taken a most active and keen interest in everything that related to the handling of grain. Since the installation of the turbos a great deal of experience had been gained. So far as his (the speaker's) knowledge went, nobody in the country had up to the present carried out any experimental work on large parcels of grain on full-sized turbo machines, and the machines which the Port Authority possessed were the only machines of that character at present at work. As Mr. Kirkpatrick had stated, Turbos Nos. 1 and 2 had been constructed, to a large extent, as an experiment. Since that date a good deal of development had taken place. The characteristics of the exhausters which were now being built were different from those of the first two turbos, and a great

deal was being learned, particularly by the makers of the exhausters. Personally, he had devoted a good deal of time to the problem; and he had also studied the difficulties and troubles experienced with the gears, to which Mr. Kirkpatrick had referred. He was satisfied that, with certain provisos, the turbo-exhauster was the thing. Those provisos were as follows—that some proper mechanism be introduced into the run of the air either to maintain a

Turbo-Exhausters. Characteristic Curves.

FIG. 19.

FIG. 20.

constant vacuum with a constant flow of air, or to prevent the quantity of air increasing beyond the predetermined amount. He had prepared graphs showing the relative characteristics of the two classes of exhausters now in use.

Fig. 19 belonged to the first sets (Turbo Nos. 1 and 2), and Fig. 20 to the second sets of exhausters which had been put in. Referring to Fig. 19, it would be found that a flow of 8,000 cubic feet of air with a vacuum of just over 9 inches represented a b.h.p. of

just over 200 with the exhauster speed of 2,700 r.p.m. If it were imagined that that vacuum was broken down through some cause or another, and had been reduced to 4 inches, the b.h.p. required would be just under 400, so that there was therefore an overload of 100 per cent, the quantity of air having gone up to something like 17,000 cu. ft., the r.p.m. remaining as before, namely, 2,700. In Fig. 20 it would be found that the exhauster had been designed so that, should the vacuum drop, the quantity of air would not increase in the same proportion, and the h.p. would not go up beyond a certain predetermined amount. That design was an excellent one, and he thought the designer was to be heartily congratulated. But it was not enough. The next thing to be done was to put into that pipe-line an effective air control.

On the subject of the output of the machine per b.h.p. per ton of grain, if anybody was interested in the matter and referred to Professor Cramp's Paper,* he would come to the conclusion that pneumatic machines were absorbing something like four times as much power as they should, if they accepted the results which that gentleman had obtained by experiments on a small scale. He (Mr. Deane) had no doubt that there was a vast amount of power expended, and so far as the mechanical efficiency of the machine was concerned, he did not think that that was of such great account, because there was a certain amount of limitation on the quantity of grain which it was desirable to put through. But where it did make a difference was in the size of the plant. Taking the particular turbos under discussion, Turbos nos. 1 and 2, the maximum quantity of grain which ought theoretically to be handled was something like 220 to 250 tons per hour. The maximum amount which had ever been handled by either of those machines, as given by Mr. Knight, was 120 tons. He (Mr. Deane) had been able to find some other data which increased the figure up to 130 tons, but it would be seen how very far short were these figures from the theoretical quantity. If, therefore, it was desirable to aim at about 100 tons per hour as a maximum, it should be possible to reduce the initial cost of the installation, and at the same time to keep down the cost of running.

Mr. C. P. KININMONT said it had been his privilege for several years to work in close co-operation with the late Mr. A. H. Mitchell, to whose genius and to his peculiarly independent judgment many of the most modern developments in pneumatic grain handling

* Journal, Royal Society of Arts, 1921, vol. lxix, page 283.

were due. He liked to think of Mitchell's work as typically British, and it was interesting to compare the developments which Mitchell had brought about with the developments which had been almost contemporaneous, or perhaps a little earlier, in Germany.

The Germans applied to the old original Group A type machines, which they manufactured under licence from Mr. Duckham, knowledge (not necessarily very profound), of thermodynamics and pneumatics, and they improved their efficiency by producing better and more efficient vacuum pumps. But the machines were left essentially of the Group A type. They made them larger to suit their conditions, but no essential change was made in the character of the machines. He thought it might fairly be said that they had applied knowledge but very little imagination, while Mitchell had tackled his work always with a critical and constructive imagination. Mitchell had taken pneumatic plants as labour-saving appliances and looked around for ways to improve their efficacy in that respect. He had found that a feature of the pneumatic plants lay in the fact that they could maintain their capacity practically from start to finish, and again he had sought means of improving their efficacy in that respect. Both those considerations had led him to apply electrical handling to the pipes, which was a drastic change, because it had affected the design in many other ways. Then again, Mitchell had looked at the costs of running the plant and had found a big loss in the consumption of coal while the plants were waiting for ships to come in, keeping up steam, and that fact had led him to apply oil-engines.

Turbos nos. 1 and 2 were typical examples of Mitchell's work. His (Mr. Kininmonth's) firm had just put to work on the River Shannon a machine which embodied ideas to meet a particular problem. The elevator had to be sea-going, and the beam was limited to 25 feet. The beam of the ordinary German elevators was 35 feet. The capacity had to be 200 tons. Mitchell suggested a pipe-handling gear, all electrically controlled, which consisted briefly of a folding cantilever support. That vessel could cross the Atlantic with everything fully rigged. Instead of being between 70 feet and 80 feet high, as the German machines were, it could pass under the squared yards of a sailing ship, and it could run its pipes out without any support for 40 feet from either side of the vessel without causing appreciable list, and get into and out of the largest ship bringing grain into the port of Limerick. He thought that was a fine example of imaginative design.

A MEMBER asked if he might make an appeal to Mr. Kininmonth,

whose firm had lately put up a coal-handling apparatus on the pneumatic system. If tests of that apparatus could yet be released, and Mr. Kininmonth could announce them in Manchester, they would be very valuable indeed.

Mr. WILLIAM REAVELL (Member of Council) said though he could not claim to have a close acquaintance with the subject of Mr. Mitchell's Paper, there were so many things of great interest in connexion with Mr. Knight's Paper that perhaps the Author of the first would not take exception to the fact that he did not discuss it. As his firm were the makers of the machine with the characteristics shown in the lower diagram which had been displayed by Mr. Deane, Fig. 20, he would like to refer to one or two features about these characteristics.

First, however, he would like, respecting Table 1 (page 920), to make a remark in regard to the h.p. of the Dolphin machines at Millwall. Mr. Knight had explained that the motors there were of 200 b.h.p. The reason why they were of 200 b.h.p. was that they were so constructed as to be able to work up to 15 inches of vacuum although the normal working vacuum was 11 inches, and with 11 inches of vacuum the input electrically to each machine was 175 h.p., and the actual b.h.p. of the motor was about 155 h.p. or 156 h.p. when running at 6,000 cub. ft. per minute on shop tests. He thought Table No. 1 was extremely valuable to everyone interested in the development of those machines from the early days, which had been referred to by previous speakers. In Table 1 the members had in a sort of historical form a great deal of most interesting data which they would be glad to have in the records of the Institution.

There was a good deal to be said respecting reciprocating machines as well as turbo machines. One might readily see, however, that with a reciprocating machine which must have suction and delivery valves, and which could not always be sure of getting the rarefied air passing in and the pressure air passing out from the cylinders through those valves perfectly clean, there was always the question of the wear and tear of the valves and of the pistons in the cylinders. In that respect the turbine machine had a great advantage inherent to that type, namely, that it had no valves at all. On the other hand, a turbine machine naturally could not be made of small enough size, with due regard to efficiency, to deal with the number of plants which were required for small capacities, and there unquestionably the reciprocating machine had its field, unless some new form of

rotary exhauster which was lighter and of higher speed could take its place.

Mr. Kirkpatrick, in his interesting remarks, had fixed upon the gears as the weak point in the turbo machines. Mr. Kirkpatrick would be the first to agree that it was not always necessary to use gears. In this country, owing to the difficulty of obtaining native-built high-speed motors of any reasonable power for continuous current, it was obvious that, where the latter was used for the prime mover, gears must be introduced in some form, but he imagined that what Mr. Kirkpatrick had in his mind was the difficulty which the Port Authority tackled most courageously, namely, the driving of a purely rotary form of machine at high speed like a turbo-exhauster through gears from a two-stroke cycle reciprocating oil-engine. It was a problem which required a great deal of consideration, because, although there was no cyclic irregularity with the turbo, this irregularity was inseparable from even the best designed 2-stroke cycle engine. Modified designs of gears, however, had now been produced which he was quite satisfied entirely overcame the difficulty. If the turbine was going to be driven by an electric motor supplied from a power station with polyphase current, then one could at once attach a two-pole high-speed motor to the shaft of the turbine, and all problems of gears were done away with; but, where a motor of continuous current was to be used and it could not be obtained of sufficiently high speed, it would be clear that the gear problem would not arise in the same way as when one strove to drive by a reciprocating oil-engine. He did not think, therefore, that any difficulty need be feared regarding gears when the prime mover was an electric motor, where, of course, there was a perfect rotary motion.

He was entirely in agreement with Mr. Deane in the views which he had expressed on the question of control. A reciprocating turbo-exhauster had the advantage that, when the nozzles—or the “elephant’s trunks,” as General Mowat called them—were pulled out of the grain, the load that was thrown upon the motor which was driving that reciprocating positive piston displacement machine was at once lightened. In a turbo-exhauster when the nozzle was drawn out of the grain the turbo was at once overloaded, as Mr. Deane had explained in his diagram, not so much in the Reavell type of turbine, but generally the machine was overloaded. Mr. Deane was quite right in considering that it was a desirable thing to use some form of control to prevent overloading. That could be done in two or three different ways. In Fig. 21 would be seen the type of characteristic which Mr. Deane had made so clear in his diagram, Fig. 20. The top curve A showed the volume-pressure

curve at the maximum speed; the middle curve B showed the volume-pressure curve at normal speed; the bottom curve C showed it at slow speed. The motor was furnished with rheostatic control, giving a total range of control of 15 per cent. Hence those three different speeds. The corresponding h.p. volume-curves were indicated as A_1 , B_1 , C_1 . By arranging the rheostatic control in a manner he sketched on the blackboard afterwards, instead of the overload, in accordance with curve A_1 , being thrown upon the

FIG. 21.—*Characteristics of Turbo-Exhauster (Reavell).*

prime mover when the nozzle was pulled out of the grain, the speed was reduced automatically by mechanism. The line D then represented the reduction in the volume, and the line D_1 represented the variation in the h.p. It would be seen that at the full volume and vacuum the h.p. was a little over 160, and it would be noticed that throughout all the range of control the h.p. never varied more than was shown by the line D_1 . Never more than the normal full h.p. was thrown upon the motor. If that could be obtained with a control of only 15 per cent, it

would readily be seen that if a motor was fitted for a control of a greater range of speed, a still greater reduction in power could be automatically attained.

Fig. 22 showed the automatic arrangement for speed control. A was the suction-pipe going to the turbo-exhauster, and B a diaphragm inserted in it; C and D were pressure-pipe connexions, which gave a slight difference of pressure due to the diaphragm, the exact difference of pressure depending upon the velocity of flow. It would be realized that when the hose was pulled out of the grain the velocity of flow was increased, and, therefore, a greater difference of pressure would be obtained across the diaphragm. That difference of pressure was used directly to operate the rheostatic controller,

FIG. 22.

FIG. 23.

so that as the difference of pressure increased, the speed was reduced. The same difference of pressure could be quite readily used also to operate a balanced throttle-valve, Fig. 23, so that the throttle-valve was at a position E under normal working conditions; and an increase of pressure on each side of the diaphragm could be used to swing the suction throttle-valve over to the closed position, shown in dotted lines. He was quite sure that something like that would be done, and done very soon, by those interested in turbo-exhausters, because it could be used with a constant speed of the prime mover. If, for example, it was being driven by a 3-phase motor at constant speed, overloading could be entirely prevented by adopting it, seeing that a variable speed control could not be used as in a continuous-current machine.

Mr. W. H. ATHERTON said he felt sorry that Mr. Mitchell's Paper had been neglected in the discussion ; not because the subject dealt with in that Paper was less important than that contained in the second Paper, but because the latter happened to be of more local interest. Probably it would have been better for the Author to have chosen a less comprehensive title and restricted himself to a few types of conveyors, so as to be able to deal with them perhaps a little more thoroughly in the limited time at his disposal. He (Mr. Atherton) had brought with him some slides of a few types of conveyors which had not been described in the Paper, though comprehended in the title. (Mr. Atherton then proceeded to throw on the screen diagrams and views of several types of conveyors and elevators. These included chain-belt conveyors of the swing-tray, finger-tray, and rigid-arm types, so useful for handling bags, bales, barrels, crates and packages generally ; also gravity roller conveyors for boxes. The importance of the continuous overlapping-bucket elevator for handling gritty and lumpy materials was emphasized and illustrated by a photograph of two large elevators arranged in series, having a total lift of 150 feet and a capacity of 250 tons of crushed nitrate rock per hour.)

Mr. GARDINER MITCHELL, in reply, said there were very few remarks he had to make, owing to the fact that there had not been very much discussion on the general types of elevating and conveying machines. It was supposed that elevators and conveyors had to give way to what is termed "more modern types of handling," such as the pneumatic plant, but this latter could only be applied for specific purposes and under certain conditions. Bucket-elevators and the various types of conveyors could be used for handling any kind of material.

With regard to Mr. Kirkpatrick's remark about timber conveying, that had been ably answered by General Mowat. Timber could be handled by ship elevators, then carried along in troughs by endless rope conveyors, having drags or claws attached to the rope. Mr. Scrutton had spoken about the matter of dealing with general cargo. There were several designs of elevators and conveyors by which general cargo had been dealt with, but the applications were so numerous that a particular kind of material would have to be named before the correct type could be recommended. He agreed with General Mowat in his remark that such appliances should not be called labour-saving appliances, but labour-aiding devices.

Mr. R. E. KNIGHT, in reply, said it would be seen from Mr.

Cecil Bentham's Paper, referred to in the Bibliography (page 931), that results were given for vertical reciprocating exhausters. The plant was at the Manchester Docks and consisted of twin vertical pumps motor-driven through 4 to 1 reduction-gear running in oil. The figures given were for a short run of 1 hour with a 60-foot vertical lift and the power consumed was 1.48 b.h.p. per ton per hour; and he considered that the figures shown in Table 3 (page 930) for the rotary exhauster compared favourably with these, bearing in mind the *average* nature of the results given.

The results of his experience in the running of the plant were in agreement with the remarks made by Mr. Deane; and he hoped that he (Mr. Deane) would complete these remarks by adding how the special features of the rotary exhauster had been, or could be, counteracted to give efficient practical working.

Mr. Kininmonth had mentioned the construction by his firm of a floating pneumatic elevator (he (Mr. Knight) believed this to be the "Garry Owen") in which the grain pipes were carried in the form of a counterbalanced cantilever supported on a luffing and slewing self-balancing jib. This feature was, of course, of extreme value from the stability point of view, and was originated by the late Mr. A. H. Mitchell on the Port Authority's bucket-elevator "Mitchell" in 1908, and was still in force.

He might refer to two points in General Mowat's remarks. First, from Table 2, (page 929) the engineering costs for the Group C Pneumatic were given as 6.9 pence per ton and for the bucket-elevator, "Mitchell," as 6.84 pence per ton; to the latter must, however, be added larger bulk grain charges for trimming the grain in the ship's hold to the elevator leg after the angle of repose for the grain had been passed. He did not think, therefore, that the bucket-elevator could be said to be cheaper than the pneumatic, quite apart from its unsuitability for dealing with cargoes separated by "matts," etc.

Secondly, General Mowat had asked for figures for the b.h.p. per ton per hour for the Dolphin plant at Millwall Docks before and after conversion of the main power plant. Prior to conversion, the figures given in General Mowat's Paper referred to in the bibliography, were from 2.5 to 3 i.h.p. per ton per hour. After conversion, the figure was within 2 b.h.p. per ton per hour, and this was an outside figure which had been and would be considerably improved upon.

With regard to the points raised by Mr. Reavell, a somewhat similar overload device, or rather air-limiting device had been tried on one of the turbo-elevators. This device, however, operated

on the differences in actual static pressures caused by the variation in vacua rather than on the Pitot tube principle as mentioned by him.

Discussion in Manchester on Monday, 19th December 1921.

Chairman : Mr. WILLIAM FOX, Member.

Mr. C. P. KININMONTH, in opening the discussion, stated that Mr. Knight's Paper was particularly interesting to him because his firm was associated with the late Mr. Mitchell in the design and construction of the Group C machines, Turbos 1 and 2, which had shown such improved results. He thought it was unfortunate that circumstances prevented Mr. Knight from giving total costs of working per ton for various machines, and that he was only able to give engineering costs. He regarded it as creditable when these costs could be reduced, but a machine should not be condemned on account of high engineering costs, provided the total costs were reduced. Comparing total engineering costs with total traffic costs, the natural tendency was for the former to increase from year to year as more and more elaborate machinery was introduced, but for traffic costs to decrease to a greater extent, giving a total decrease in costs. The Paper indicated that the traffic costs for Turbos 1 and 2 were no higher than those for the older machines, for an important item in traffic costs was labour used in manipulating the pipes, and it would be noticed that Group C machines gave practically the same capacity as older machines and were fitted with two pipes instead of four. The labour in the hold of the ship was consequently halved, and the traffic costs considerably reduced. He (Mr. Kininmonth) had had experience of machines of a similar type to that described by Mr. Knight, which had regularly averaged, on the discharge of a whole ship, 100 tons of oats, which was equivalent to 140 tons of wheat, per hour. This average, however, could not be attained with the delivery conditions obtaining in the Port of London, where, as in most other ports controlled by public authorities, the engineer had no control over the arrangements made for getting the grain away from the elevators, and there was a hiatus in organization at the point where engineers left off and traffic men began.

From the engineer's point of view, he thought the most interesting question raised was the substitution of the turbo-exhauster for the reciprocating pump. Improved results had been

obtained by means of turbo-exhausters, but in practice still better results had been obtained by the substitution of reciprocating pumps of a modern vertical design for the old horizontal pumps, so that the minds of engineers concerned in this matter were agitated by this question as to whether the turbo-exhauster or the reciprocating pump should be adopted. The reciprocating pump had proved itself, whereas the turbo-exhauster had not. It had revealed possibilities, but there were difficulties which were not yet quite satisfactorily overcome.

Referring to the volume-pressure curves of a turbo-exhauster, he pointed out that under ordinary working conditions, when the capacity might be considerably below that expected, more h.p. was being used than was necessary, owing to the vacuum being lower. That could be guarded against to some extent by the adoption of a device such as that shown by Mr. Knight. In the reciprocating pump, however, it was certain that the h.p. would fall the moment the vacuum and the capacity were reduced. There was also trouble when working at high capacity. As the curves showed when working near the maximum vacuum, a very slight increase in vacuum, that is, in grain load or resistance of pipe-line, would cause an enormous falling off in volume, and hence a plant operated by a turbo-exhauster would be very much more liable to choke when driven at all hard. This trouble had probably not been experienced in the Port of London because, as the Author's figures showed, the plants there were not driven hard as a rule. But it should be remembered that the harder such plants were driven the more efficient they were. In these two respects the turbo-exhauster, even when fitted with automatic-speed adjustment, which was not always possible, could only do the same as the reciprocating pump, and within narrower limits. But on the other hand, the turbo-exhauster had an advantage in that it was a very simple and compact mechanical device, and unlike the reciprocating pump, it produced no alternating stresses in the structure upon which it was erected. It was, therefore, very useful on floating and travelling machines. That was why there was good reason for further experiment on the possibilities of the turbo-exhauster for this class of work.

He was particularly interested to notice the figures given by the Author covering the cost of maintenance of the various types of machines, from which it was apparent that the maintenance costs of pneumatic plants compared very favourably with that of bucket-elevators. It used to be believed that the reverse was the case, and the makers of pneumatic plants had had some difficulty in

persuading users that they would find their maintenance costs at all events no higher. The publication of these figures which were, he believed, the first properly authenticated figures to be published, showed that in putting their case no higher than that, the makers of pneumatic plants had been unnecessarily modest.

Mr. JAMES WHITAKER said the question of pneumatic elevating of grain had agitated the minds of engineers for a long time. One had only to look through the Patent Office records to see that fifty or sixty years ago, and at frequent intervals since, engineers had been at work on this problem. It was an unfortunate circumstance that the experimental data collected by the earlier workers were not recorded so as to be available for subsequent workers. The result was that the failures of one set of engineers were repeated by others who worked over the same ground. Many independent workers had tried the fan or turbine type of exhauster, and he (Mr. Whitaker) considered that the question of this type of exhauster versus the piston or constant-displacement pump had long ago been decided in favour of the latter. There were apparent advantages in the turbine-pump, inducing engineers to employ it in preference to the constant-displacement pump. One of these was its higher efficiency. A single-stage turbine fan could have an efficiency going up to 80 per cent, whereas the efficiency of the reciprocating exhauster might not be more than 40 per cent. In spite of this and other advantages, the volumetric instability of the turbine-exhauster was such an objectionable property of this type of exhauster as to be decisive against its use. He (Mr. Whitaker) had had to do some years ago with a pneumatic elevator employing a turbine-exhauster producing a partial vacuum or depression of $2\frac{3}{8}$ inches of mercury. The vacuum or depression remained much the same whatever quantity was being elevated. It was, in fact, only dependent on the speed of the exhauster. The maximum elevating capacity of this installation was 40 tons of wheat per hour. It took 96 h.p. and delivered 6,720 cu. ft. of air per minute, and the temperature of the air delivered from the exhauster was found to have risen by 32° F. in passing through the exhauster. This great development of heat was the cause of much loss of power; in fact it was calculated that more than half the power used was carried away as heat added to the air. Immediately the suction-pipe was lifted out of the wheat, or when all the wheat had been lifted up, there was an enormous augmentation of the volume of the entering air and a simultaneous increase in the power taken. The volume of the air when no wheat was passing was found to be

16,000 cu. ft. per minute and the h.p. 130. An easily worked damper was included in the installation for checking the flow of the air under these circumstances, but this did not overcome sufficiently the possibilities of waste of power and violent fluctuations in the load.

One might contrast this turbine-exhauster installation with another installation having a pump of the constant-displacement type. In the latter he (Mr. Whitaker) found the vacuum in the receiver was 3 inches of mercury when elevating the maximum quantity of 20 tons of wheat per hour. With no wheat entering the suction-pipe, the vacuum in the receiver fell to $1\frac{1}{2}$ inches of mercury, thus greatly reducing the power taken when no wheat was being elevated. The volume of air entering the suction-pipe when no wheat was passing he ascertained by means of Pitot tubes to be 3,600 cu. ft. per minute. Under no circumstances could this volume or displacement be exceeded. He thought the reciprocating exhauster a practical and simple machine, and, in spite of a somewhat low mechanical efficiency, its use gave working results which were sufficient and satisfactory in ordinary practice. He asked the Author if he could state briefly what had been the saving in power due to the replacement of the reciprocating pumps by rotary exhausters.

With regard to Mr. Mitchell's Paper, there were many different trades using conveyors and elevators, and it was unusual to find anyone who was acquainted with the practices of all the trades. The formula shown by Mr. Mitchell on the screen relating to the power taken by a bucket-elevator made the power proportional to the height. Strictly speaking, this was not quite correct. For instance, in an elevator 20 feet high a certain amount of power was due to the drag of the buckets in picking up the material in the elevator boot. When the height of the elevator was, say, 60 feet, the frictional resistance in the boot was still the same. This fact should be allowed for in the formula.

With regard to feeding arrangements in elevator boots, the reciprocating ram feed was much used in feeding coal-elevators, and was found to be effective in preventing chokes and saving power. This device had not been mentioned by Mr. Mitchell. The speaker also described by a sketch how choking an elevator could be prevented and a steady feed assured by feeding the material down a slope with inclination not much greater than the angle of repose of the material.

Mr. G. W. WHITE did not think that conveying machinery could

be divided into nine classes. He was of the opinion that the spiral, screw and paddle conveyors should be coupled together as one type ; also the push-plate and drag-link conveyors.

With regard to the rotary feeder, he thought that the one illustrated in the Paper would only work on small material, and asked for some particulars as to the material suitable for this feeder.

With regard to Appendix II (page 908), he asked why the Author recommended 5-inch rollers for a 12-inch conveyor, and 9-inch rollers for a 48-inch conveyor. In Appendix IV (page 910), the Author stated that the speed for a belt 12 inches wide was 200 feet per minute, while that for a 48-inch belt was 500 feet. Had the Author any reason for difference in speeds for different widths of belt ?

Mr. T. T. HINDLE asked if Mr. Knight had had any experience with a Roots' blower. The speaker had seen an installation exhausting ashes and clinkers from boiler furnaces. The horizontal pipe was 12 inches diameter by 63 yards length ; the clinker, etc., was fed by means of hoppers into openings in the pipe and drawn into a cyclone separator, the air vapour and light dust being drawn from the top of the cyclone through the blower and was then blown into an air-chamber where it accumulated as sludge. The blower was direct-coupled to a 72 h.p. electric motor running at a speed of 285 r.p.m., and the pressure-gauge registered from 2 inches to 4 inches of mercury.

The 200 h.p. referred to in the plant described on page 922, he thought somewhat excessive, and the 80 per cent efficiency given for the exhaustor by Mr. Whitaker seemed rather high.

Mr. WILLIAM FOX stated that the Manchester Ship Canal Co. used extensively all kinds of machinery for discharging, loading, conveying and distribution of grain. The most efficient and economical method of discharging grain in bulk was by means of the bucket-elevator, but this method proved expensive for cleaning-up purposes when the grain had to be trimmed by powershovels or by hand to the elevator-boot. However, used in conjunction with a pneumatic plant, which was specially serviceable for cleaning up purposes, one had an ideal combination. Quantities of grain, however, were loaded in vessels in small parcels separated by mats, and as each parcel had to be separately unloaded, the pneumatic plant was here unrivalled. The Manchester Ship Canal Co. had two grain-elevators at the Port of Manchester.

No. 1 Elevator was built by Messrs. Metcalfe and Co., of Chicago,

and was equipped for discharging with a bucket-elevator and a modern pneumatic plant, which together were capable of discharging bulk grain at the rate of 470 tons per hour, the grain averaging about 110 tons per hour, including cleaning up the holds, and having a maximum capacity of about 140 tons in bulk.

The grain at No. 2 Elevator was discharged from vessels lying in berths along the whole length of the dock on to subway bands either by a floating pneumatic plant, at 250 tons per hour, or by smaller portable bucket-elevators.

The pneumatic plant at No. 1 Elevator was of the vertical reciprocating pump type comprising two vertical pumps running at 125 r.p.m. driven from a common crank-shaft by a 240 b.h.p. electric motor, running at 500 r.p.m., through double helical cut gearing running in oil. This pneumatic plant was installed about 1912, and replaced a horizontal plant which was similar to those installed by the Port of London Authority at Millwall. The existing canisters and pipe-lines were utilized, the tripper-boxes being replaced by rotary seals, and experience had proved the new plant to be the most economical type in use. Experience with the old type of reciprocating pneumatic pumps with the attendant heavy maintenance costs, especially valve maintenance, had led many people to believe that the modern vertical type of pneumatic plant was also costly in this respect, but this was not the speaker's experience. The average maintenance cost of valve renewals has not exceeded £3 per annum.

Referring to Fig. 4 (page 896,) of Mr. Mitchell's Paper, showing a cross-section of an arrangement of rollers, conveyor-belts and concentrators, this arrangement gave one the impression that the maintenance cost of the belts would prove expensive. The method of lubrication was ingenious, but did not appear to be so economical as ring oil-bearings. In the Grain Elevator No. 2, previously referred to, the bearings were self-swivelling, self-aligning ring-oil type, totally enclosed and dust proof, and when filled with oil required no attention whatsoever for a considerable period. As there were many thousands of these bearings in use, it would be appreciated that the saving in attendance costs was considerable. Stauffer lubricators had proved effective and were largely in use, but they required considerably more attention.

The CHAIRMAN, Mr. Fox, in moving a vote of thanks to the Authors, complimented them on their Papers.

Mr. GARDINER MITCHELL, in replying to the discussion, stated

that he had omitted to mention interesting figures on the life of a push-plate conveyor. One of these his firm (Barry, Henry and Cook, Ltd.) had installed in Aberdeen had handled 258,393 tons of coal during the seven and a half years it had been in use, without a renewal. He also mentioned in regard to saving of labour, the case of a paper mill, where thirty men were employed supplying coal to a boiler-house plant, working three shifts per day. After the installation of conveyors and elevators, the number of men was reduced to twelve.

With regard to Mr. Whitaker's remarks re the formulæ for h.p. for elevators, he (Mr. Mitchell) had tested the formulæ against twenty years' experience. He found that the effect of the difference in the height of the elevator on the h.p. was the main factor to be taken into account, but the effect of the friction in the top and bottom fittings was infinitesimal, and could be discounted. His Paper had not been printed in full,* thus explaining the absence of details of feeds, but other types were prong, shaker, plunger, rotary, pusher. He disagreed, however, with Mr. Whitaker as to the efficiency of the feed illustrated by him, as the loading of material was bound to continue between the buckets, which would gradually cause a choke.

He did not agree with Mr. White that the screw, spiral, and paddle conveyors all belonged to one class; nor were the push-plate and drag-link conveyors both one type. Each was an entirely different type, used for quite different purposes, and had no characteristics in common; therefore he felt justified in putting each conveyor as a separate class. With regard to the class of material for which he had used the feeder illustrated, he had installed it for coal, coke, ashes, sand, broken brick, iron ore, and other similar substances, all being the worst kinds of material to handle.

The Tables in the Paper were compiled as a result of practice, based on the most exhaustive calculations, and he had found that 5-inch rollers for a 12-inch conveyor, and 9-inch for a 48-inch conveyor were the sizes whereby the least possible wear was obtained, taking into account the width of the band, the weight of the material, and the speed of the conveyor. A conveyor could be run at practically any speed, but the speeds given in the Table were those he had found most suitable for the size of the conveyors.

In replying to Mr. Fox, the Author said that although screw-gear was still being installed, he recommended the latest type of

* The original and complete Paper is preserved for reference in the Institution Library.

tipping gear, which was the barrel type. This consisted of an anchored rope at the top of the pit, going down and round a pulley at the bottom of the hoisting frame and on to a barrel driven by a worm-gear. This arrangement was in use in a large number of works, and was more efficient than hydraulic and screw-gears.

With reference to the lubrication of belt-conveyor rollers, Mr. Mitchell said he was not an advocate of Stauffer lubrication, although his drawings showed this type; these figures were illustrative only, but the bearings were of the dust-excluding type. The most efficient type of carrying rollers were those fitted with ball-bearings, and the Author always fitted these or the ring-oiling type when high-class conveyors were specified.

Mr. R. E. KNIGHT, in reply, stated that he agreed with Mr. Kininmonth that bulk grain costs, as apart from engineering costs, materially affected the comparison between bucket and pneumatic elevators, and to a minor degree that between different types of pneumatic elevator. He regretted that he was unable to give bulk grain costs; but he might say that for the normal grain cargo to be dealt with in the Port of London these charges would be lower for the pneumatic than the bucket elevator. On the Group C turbos when working, the engineering crew was three men, and the bulk grain crew twenty-two; there were only two pipe-lines on these machines against either four or eight on some of the others.

Mr. Kininmonth had raised a point in connexion with the curves shown in the Paper as to what might happen to the rotary exhauster if a choke in the pipe-lines were maintained and a higher vacuum and consequently lower air quantity were reached than the machine was designed to deal with. He (Mr. Knight) had consulted with the designers on this point, and was of opinion that (a) the h.p. required would be reduced to a minimum for the speed, (b) the condition known as "surging" would be set up, and (c) the working conditions of the exhauster might be reversed, the "choke" being thereby automatically ejected. None of these effects should be to any extent harmful to the plant as a whole; whereas, with a reciprocating exhauster of either the horizontal or vertical type, a maintained choke might lead to heavy overloading and damage to the plant.

Mr. Whitaker had asked why rotary exhausters had been fitted instead of vertical pumps, and in this connexion he might briefly enumerate some of the advantages of the rotary type for a pneumatic plant: (1) Minimum headroom and space occupied in the hull or on the quay; (2) weight; (3) cost; (4) absence of vibration;

(5) minimum maintenance, there being no valves to renew, pistons to repack or cylinders to rebore; (6) light foundations; (7) speed-increasing gears were required with an oil engine, but speed-decreasing gears would also be required for a reciprocating exhaustor, unless the number of barrels were multiplied and the maintenance of the working parts therein increased thereby; (8) efficiency *when new* would be lower than the pump, possibly 75 against 85 per cent; but the rotary should maintain its 75 per cent for long periods without attention, whereas the 85 per cent for the pump would be rapidly reduced with use; (9) attendance was a minimum and no water-jacketing was required; (10) with one or more of the air control or limiting devices referred to in the Paper and the Discussion, the chief and, in fact, the only objection to the rotary type (that is, increase of loading for the removal of nozzle from grain) could be counteracted.

It was interesting to note that in Mr. Bentham's Paper, read at Manchester in 1916, the following figures were given for the twin vertical pumps motor-driven through 4 to 1 reduction gear running in oil, as installed on the Manchester Ship Canal. In this plant there were forty suction and forty delivery valves per pump, or 160 valves in all. The figures were for bulk wheat with a 60-ft. lift and a one-hour run, the quantity being 142 tons and the b.h.p. per ton-hour = 1.48. Bearing in mind the *average* nature of the tests given in the Paper in Table 3 (page 930) for the rotary exhaustor, he thought they compared favourably with these figures. It would be seen from the Paper that the cost of maintenance of the rotary exhaustor, as such, over a period of six years was nil.

In regard to the valves, Mr. Fox had stated that the average annual renewals were three to four at 3s. 6d. each and that the cost of maintenance for this item did not reach £3 per year; and in view of the large number of these involved (namely, 160) he thought this was a result on which Mr. Fox was to be congratulated.

Communications.

Mr. H. HAERLE (Messrs. Reavell and Co.) wrote that he wished to confine his remarks to the question of efficiency raised by Mr. Knight's Paper. The Author stated (page 918) that the efficiency of a pneumatic elevator was usually about 5 per cent, or even less, and the question naturally arose, what was the cause of such low efficiency? The writer could not claim to have sufficient knowledge

of pneumatic elevator plant to give a complete answer to this question, but as a specialist in compressor work, he was concerned chiefly with the efficiency of the exhauster.

The turbo-exhauster as supplied by Messrs. Reavell and Co., Ltd., to Millwall Docks, was put through a series of exhaustive tests prior to despatch, and Mr. Deane had already shown the resulting characteristic curves which were obtained. Fig. 24, showed,

FIG. 24.—Performance of Millwall Dock Exhausters on Test Bed.

together with these curves, the corresponding efficiency curves. It would be seen that at the designed output of 6,000 cu. ft. per minute the adiabatic efficiency was about 77 per cent to 80 per cent. This value remained fairly constant over a considerable range of volume and vacuum, and this efficiency compared very favourably with the corresponding efficiency of a reciprocating vacuum pump.

On the other hand, the writer's firm had recently completed a turbo-exhauster to be used for grain elevation, in which the adiabatic

efficiency had reached the very high value of 88 per cent, and in this respect clearly exceeded the efficiency available from the most modern vertical reciprocating type. These efficiencies also proved that the blame for the low overall efficiency of a pneumatic elevator could not be laid at the door of the exhauster when properly designed for the purpose. Clearly, the causes for low over-all efficiency must lie elsewhere, and in all probability considerable improvement

FIG. 25.—Comparison between Reciprocating and Turbo-Exhausters.

could be effected by redesigning the grain-nozzle, as well as proportioning suitably the pipe diameters of the suction-pipe and reducing the number of bends to a minimum.

An objection which was raised against the turbo-exhauster was that when withdrawing the nozzle from the grain, there was a fall in vacuum which reduced the power absorbed by the reciprocating type, and produced an over-load on the turbo-exhauster. The periods during which the nozzle was clear of the grain were very short compared with the total duration of unloading a grain

vessel, so that the percentage of extra energy due to excess h.p. was a very small fraction of the total number of units consumed, and the construction of the diffuser as employed in the Reavell compressor effected a considerable reduction in the amount of overloading. Fig. 25 gave the relative performance curves of :— (a) a reciprocating exhauster ; (b) a turbo-compressor having no diffuser blades, and (c) a turbo-compressor of the Reavell type. The corresponding h.p. curves in relation to pressure were also shown. In a reciprocating exhauster the characteristic was almost a vertical line : the h.p. curve showed a decrease in h.p. with a falling off in vacuum. The two turbo-compressor characteristics were similar to those which Mr. Deane showed, but in the Reavell turbo-exhauster the characteristic approximated pretty closely to that of a reciprocating exhauster beyond the normal working volume which in the diagram was taken at 6,000 cu. ft. of aspired air at a vacuum of 10 inches. Assuming that the nozzle had been lifted clear of the grain, the result would be that the vacuum would fall to about 4 inches. With the reciprocating compressor the h.p. would be reduced from about 130 h.p. to, say, 60 h.p. In the case of the turbo-exhauster the h.p. actually increased, but while in the ordinary type “b” it would rise to about 225 h.p. as the curves showed, its rise would only be to 170 h.p. in the type “c.” The steep performance characteristic “c” possessed the advantage of acting as an automatic safeguard against undue over-loads, and rendered the suggested forms of automatic control less important when handling bulk grain cargoes. On the other hand, with divided grain cargoes h.p. control by speed reduction was quite feasible and efficient.

Mr. MARK JENNINGS (Robert Boby, Ltd.) wrote that the total cost per ton for the Turbo 1 plant (page 929) appeared very low compared with the five preceding machines, and he thought it might be largely due to its having a more efficient prime mover, namely, the four-cylinder, semi-Diesel engine. He inferred that the sharp reduction in wages cost was directly due to this, but it would be interesting to know the proportion which the pneumatic maintenance in the first five plants bore to the total maintenance given.

The Author stated that the tests given in Table 3 (page 930) were working figures, and included the usual every-day working losses. As far as capacity was concerned, there was no more difference between these and the year's working than one might expect, but the average fuel consumption for the year was nearly 25 per cent

in excess of that shown in the tests, and the average b.h.p. per ton per hour for the year was 2.3 against 1.9. These figures seemed excessive for such up-to-date plants, and could probably be accounted for by the fact that the plant was seldom working up to full capacity. It was interesting to learn how the auto speed-control on the Dolphins had increased the efficiency of this group of machines.

He did not think that automatic throttling could be seriously advocated where direct-current driving was out of the question, until all the possibilities of flexible and variable-speed gears had been exploited. Since the introduction of the pneumatic conveyor, there had always been the tendency to increase the working vacuum, and while he considered 14 inches Hg. to be the maximum practicable vacuum for an intake plant, both theory and practice went to show that increasing the vacuum also increased the efficiency. A high vacuum must always be accompanied by a certain amount of fluctuation, and whereas the power consumed by the reciprocating pump was governed by the amount of useful work actually being performed, the turbo-exhauster could only partially adapt itself in this respect. Where economy in space was not the governing factor, he thought the modern vertical short-stroke exhauster would continue to hold its own with the turbo machine, at least until such time that the efficiency of the latter was maintained at all pressures. The writer knew of a plant fitted with vertical reciprocating exhausters which was in constant use, never working less than thirty hours per week, and sometimes as much as forty, and neither the valves nor the piston of the pump had received any attention for the past eighteen months.

Captain J. E. LISTER, late R.A.O.C., wrote that there was one point in Mr. Mitchell's Paper to which the writer would like to call attention. In dealing with gravity bucket-conveyors Mr. Mitchell stated that this was practically the only type of conveyor which would deal successfully with gritty or hot materials. Tray-conveyors had been used largely for dealing with coke, which was one of the most difficult materials to handle successfully, and a firm with which the writer was connected for several years had installed many conveyors, aggregating several miles in length, on a modification of the drag-link system, which handled very successfully red hot coke and ashes. This was the conveyor known by the name of its inventor, M. J. de Brouwer, late gas engineer at Bruges.

In the case of elevators for heavy duties, if reliability and not first cost was considered to be the most important feature, a

manganese-steel chain was a good investment, and was practically indestructible. A reciprocating type of feeder, with means of adjusting the throw and consequently the amount of material fed in, was very suitable for regulating the delivery to the elevator boot.

Another type of conveying and elevating plant, not mentioned by Mr. Mitchell, which was particularly suitable for certain conditions, such as transporting coal or other bulk materials from ships or barges to storage bunkers or yard, was the Transporter or Telfer. This could be combined with an automatic track-weighing machine to record the actual amount of material handled. An interesting example of this type of plant was installed a few years ago at the Hackney Electricity Works.

With regard to the diagrams shown by Mr. Deane of the performance of the turbo-exhausters described in Mr. Knight's Paper, it would be of interest if Mr. Reavell would explain whether the rapid drop in pressure beyond the working point was obtained by a very pronounced backward curvature of the rotor-blades, or whether it was obtained by throttling the passages of the rotor at some other point. A similar effect was produced in certain types of centrifugal pumps.

Major M. DU-PLAT-TAYLOR, R.E., wrote that several special types of elevator had been adopted for particular purposes, such as the discharge of frozen meat, for which cantilever-arm elevators or canvas-sling elevators were used. The writer had always been struck with the loss of power involved in the use of the ordinary quay crane in docks, etc. The crane had to lift its load from the bottom of the ship's hold to a considerable height to clear the ship's hatches, and consequently a considerable height above the quay, or delivery, level. The energy stored by raising the load to this height was then dissipated by lowering the load to the quay level, whence it was removed by manual labour either to barges or railway trucks or into the shed or warehouse for storage. If, on the other hand, elevators and conveyors were used, the energy stored by raising the weight to the necessary height would be sufficient to carry the load to a considerable distance by gravity, and part of this energy could be employed to assist in working the elevator.

The objection raised to elevators and conveyors in the Port of London and some other ports was that the goods in many cases had to be sorted to marks, and therefore continuous delivery was impracticable, and that the output of cranes had to be throttled to allow of this process. If, however, the sorting of goods was carried out on an upper floor, delivery to rail trucks or barges could

FIG. 26.—Discharging ex Ship.

FIG. 27.—Loading Cargo.

still be made by gravity, and the lower floor could be used for outward cargoes which did not require sorting. In Figs. 26 and 27 a typical dock quay was shown with a vessel alongside, in which A was the unloading elevator and B the unloading conveyor, these being geared together so that the delivery of loads by gravity on the conveyor assisted the elevator. C was a gravity roller-conveyor delivering from the upper sorting floor to railway trucks in rear of the sheds, and D was a similar conveyor delivering to barges from the sorting floor, the barges coming alongside the quay after the ship had left. The upper floor was devoted entirely to sorting and delivering the inward cargo, but whilst this was in progress the next outward cargo was being received and stored in the lower floor.

In the second section was shown the state of affairs during the delivery to the ship of the outward cargo, in which E was a slat-elevator delivering to F, a cantilever arm lowering apparatus, which was geared to E, so that the benefit of the drop from quay level to the bottom of the hold was obtained in reduction of power required for driving E. These diagrams were self-explanatory, and an ordinary quay-crane was shown in dotted lines for comparison.

Mr. E. G. WALKER wrote that he was disappointed to find that two classes of conveyors in which he had some general interest were not included in Mr. Mitchell's Paper. Whilst belt-conveyors were described and particulars given of two types of rubber belt, no reference was made to the use of steel belts, which represented one of the newest developments in this type of conveyor. The steel belt-conveyor, which originated in Sweden, has been used in Scandinavia for some years and has been introduced with some degree of success into this country since the War. The steel belt possessed the advantage that it might be used for warm material, provided the temperature did not greatly exceed the boiling-point of water. It was claimed that it was economical in operation and could be used under conditions involving fairly rough handling and exposure to weather.

The Author stated (page 899) that the gravity bucket-conveyor was practically the only type that could be used for gritty or hot materials. He had, however, entirely ignored the modern improvements that had taken place in the vibrating trough type of conveyor which was now in successful use for this class of material. This conveyor was continuous in action and required a comparatively small amount of power to operate it. In conveying hot materials, it possessed advantages over the bucket-conveyor in cases where

it was desired to cool the material as far as possible before storing it, in that the process of continuous projection of pieces of material along the vibrating troughs gave a far better opportunity for cooling as well as for sorting material before it reached the delivery end of the conveyor. This type of machine had been in use for many years in collieries for sorting out coal, but had been improved on a good deal recently.

The Author's classes Nos. 1, 2 and 3 were in reality one type of conveyor modified to suit different conditions, and could all be classified as worm or spiral conveyors. Conveying machinery, unfortunately, appeared to fall into the category of the rougher class of heavy machinery, which did not arouse so much academic and scientific interest as machinery of a more exact nature. Hence, excepting only in the case of pneumatic conveyors, and possibly to some extent also of belt-conveyors, very little work appeared to have been done to improve design on scientific lines, with the result that, in general, efficiencies were low and design was mainly on an empirical basis.

Mr. R. J. N. WILLCOX wrote that he had seen grain being discharged at Bremen from a steamer by means of an ordinary centrifugal pump, driven by a steam-engine. It would seem to be impossible that a solid column of grain some 30 feet long in the suction-pipe could have been kept in motion solely by pressure head generated by the pump, because of the pipe friction and the internal friction in the stream of grain. The specific gravity, the shape and the character of the surface of the grain seeds, had a material influence in determining the most effective density and velocity of the air current, because the effects of impact and frictional impulse derived from the air-current were relatively dependent upon those features. He thought a good deal of research work had been done recently at Liverpool on this subject, and in practice it was recognized that the best results were to be got by the use of different degrees of exhaustion for different types of grain. He emphasized the great importance of maintaining the appropriate velocity of the air-current, the density being of lesser import so far as propelling the grain was concerned. The pipe friction, however, was much affected by velocity, and the necessity for compromise resulted in a determination of the best conditions from experience. The reciprocating exhaustor running at constant speed was, to a large degree, self-regulating in respect to velocity of air-current, and the power absorbed by it was directly proportional to the degree of exhaustion in the system.

With the centrifugal machine the density of the fluid with which it operated was of importance. If the machine were supplied with fluid of greater density than was appropriate, excessive overload was to be expected. On the other hand, should the fluid become unduly attenuated, a critical stage might be reached when the terminal pressure was insufficient to overcome the external head, delivery would cease, and no work would be done beyond that due to churning within the pump itself. Tendency towards the latter characteristic might be checked by designing the pump to work with lower density (higher vacuum) than the average conditions required, but only at the expense of absorbing more power at the average conditions than would otherwise be required and with an increased tendency to heavy overloads.

The "surging" mentioned by Mr. Knight, he understood, referred to very rapid alternations between minus and plus pressures in the discharge-pipe from the turbo machine, and he suggested that this "surging" was the external indication of working at the critical stage and of the repeated collapse of the system. Every "surge," if his conjecture were correct, resulted in violent oscillation from no load to heavy load on the gearing. This would account for the difficulty with the gearing referred to by Mr. Kirkpatrick, and the internal-combustion engine was absolved.

The failure of the keys and keyways in the couplings by shearing could probably be obviated by the introduction of a friction clutch. This would permit of the turbo being very gradually brought up to speed at starting and so avoid heavy stresses due to inertia. A means (such as automatic speed-regulation) for avoiding excessive power overloads when working at low vacuum, and some other device (possibly in the form of a supplementary air-inlet) for avoiding a tendency towards important reduction of velocity in the air current, when the vacuum was unduly increased through choking of the nozzles, would possibly be advantageous. He estimated the coal consumption of the old horizontal slow-running steam plants, when including stand-by losses, at 4 to 5 lb. per i.h.p. per running hour. It was doubtful whether the air efficiency of the turbo operating under favourable conditions could be much higher than that of those large reciprocating pumps. It would almost certainly be less than that of good quick speed vertical pumps. One was thus led to the opinion that the very high thermal efficiency of the oil-engine, with its accompanying elimination of stand-by losses, might more than account for the reduction of fuel consumption shown by the turbo plants.

The great simplicity of rotary machines and the elimination by

them of the risk of breakdown went a long way to counterbalance any possible deficit in theoretical efficiency. Furthermore, the turbo-exhauster had been found to be unaffected by the dust-charged air, and its cost of maintenance was negligible. The components of high-speed rotary pumping machines were very small and simple as compared with reciprocating machines. Whenever important repairs might be required, the cost of restoration to full efficiency must be much to the advantage of the former, particularly so when the value of time was taken fully into account.

Mr. GARDINER MITCHELL wrote that most of the types of conveyors illustrated by diagrams and slides by Mr. Atherton had already been comprehensively dealt with in the Author's complete Paper (which is preserved for reference in the Institution Library); the others shown had not been considered by the Author, owing to the types being out of date.

In reply to Captain Lister, the Author confirmed that the gravity bucket could deal most successfully with gritty and hot materials. Tray-conveyors were used for this duty, but the wear and tear were much greater. The Author had installed a considerable number of drag-link conveyors for coke and ashes, and the initial cost was less than that of a gravity bucket, but the renewals and upkeep were very much greater. For heavy duty elevators it was to be recommended that the chains should be of manganese steel, which was mentioned under the sub-heading of Chains; the teeth and corners of chain-wheels should be made separate, renewable, and of manganese steel.

The Author, in his reply to Mr. Whitaker at Manchester, dealt with the various types of feed-gear. In regard to the Telpher plant at Hackney, the Paper had been confined to continuous methods of moving material, and Telfers or transporters were intermittent methods.

Major M. Du-Plat-Taylor drew attention to a very important point, namely, the great loss of power and time in the use of cranes; elevating and conveying methods were continuous, while cranes were intermittent. The Author was aware that a plant was fitted at a warehouse wharf on the Thames, where all sorts of packages, such as boxes, bundles, bags, barrels, etc., were loaded on slat-conveyors on a wharf or pontoon, where they were conveyed sufficiently high to deposit on gravity roller-conveyors, towards the quayside, round corners at two right angles and into the warehouse, where they were raised by a swing tray-elevator and delivered to any floor required. At this same warehouse the goods

were despatched from the various floors by spiral chutes fitted with retarders. The plant described by Major Du-Plat-Taylor appeared to be a well-designed application of elevators and conveyors.

In reply to Mr. E. G. Walker, the steel belt-conveyor had been applied by the Author and had given good results; one great drawback was the one mentioned by Mr. Walker, namely, inability to deal with hot materials. This type was more susceptible to climatic changes, and rough handling was detrimental. The question of suitability of gravity bucket-conveyor for gritty and hot materials had been dealt with in replying to Major Du-Plat-Taylor. The vibrating trough-conveyor was much more liable to wear and tear under such conditions due to excessive friction in the material moving along, and this disadvantage was not balanced with the advantage of cooling which the writer claimed.

Regarding Types 1, 2, and 3 being one class, the Author dealt with this in his reply to Mr. White at Manchester. He could not agree with Mr. Walker that conveying machinery was classed among rougher machinery; it certainly appeared to have fallen into that category, but the writer himself had indicated a new type in the steel belt-conveyor. The design of conveying and elevating machinery was highly scientific, which was evidenced by the application of ring-oiling, ball and roller bearings, also cleaning brush gear for chains and belts, automatic oiling arrangements for chains, anti-friction rollers on chains, manganese steel chains and chain wheels with renewable manganese steel corners and teeth and numerous other features in improved design—based entirely on scientific lines. This could be most thoroughly accomplished where first cost was not the main consideration, but rather the running cost and upkeep were of prime importance.

Mr. R. E. KNIGHT wrote, in reply to Mr. Haerle, who had raised the point of the low over-all efficiency of pneumatic elevators (about 5 per cent), it was agreed that the air-exhausting plant (of whatever type) was not responsible for this defect; it was solely a question of the very small proportion of grain to air which was raised by the grain-handling portion of any pneumatic plant. This proportion was of the order 1 to 40 or 50 under good conditions. Various experimental results on small model plants had been published which showed a better figure than this; but he thought none for full-size plants under working conditions. The Port Authority were at present carrying out very exhaustive tests on one of the Group C machines with a view to determining whether this proportion could be improved on for practical working.

Mr. Jennings was correct in attributing the major portion of the reduced total cost per ton shown by the Turbos in Table 2 to the avoidance of stand-by and maintenance charges with the oil-engine prime mover; this was the obvious reason for its installation as stated in the Paper. He (the Author) was not clear as to what was meant by "pneumatic maintenance," but, if this referred to the grain-handling superstructure only as apart from the hull upon which it was carried and the machinery by which it was operated, he regretted that the figures were not available, nor would they, in his opinion, be of value in comparing the respective merits of the three groups of machines. Mr. Jennings had taken the fuel consumption for the year 1919-20 as given in Table 2 (page 928), and from it he had obtained figures for consumption and estimated brake horse-power which exceeded those given in Table 3 (page 930), being tests taken in 1921. This was not surprising, as the year's figures included the whole fuel burnt by the main and auxiliary engines during the year irrespective of whether grain was being raised or not; whereas the test figures in Table 3 were stated to be for "net times." The remark as to auto speed-control presumably referred to the switch-gear for the Millwall plant not being described in detail on page 926 of the Paper.

In regard to automatic throttling or air control, the condition in the rotary exhauster which required such an arrangement would not appear to be removed by the use of either a flexible or a variable speed-gear, although its effect on the remainder of the plant might be; and in this connexion such gears as the "Matteucci" would appear to present considerable advantages.

Considering the question of the degree of vacuum to be adopted, it would be seen from the curves shown by Mr. Deane (page 938) that at any speed for the rotary exhauster, the horse-power required *decreased* with *increase* in vacuum; whereas for the reciprocating exhauster it *increased*. The advantage at high vacua when working would therefore appear to lie with the rotary exhauster. The practical consideration of selecting such a range of vacua as was suitable for all classes of grain both heavy and light, and at the same time obtainable from the available speed range on the oil-engine prime mover must not be neglected in a plant of the Turbo type.

Mr. Willcox mentioned the case some years ago of grain being pumped out of a ship at Bremen by a centrifugal pump with a 30-foot lift and no grain nozzle or air sleeve, the grain presumably passing direct through the pump. A reference to the late A. H.

Mitchell's Paper* would show that this had been tried some years ago without success ; the grain had only been raised about 5 feet in the pipe, and, if raised the whole distance, would presumably have been prematurely converted to flour in the pump. He (the Author) was of the opinion that the operation was not effected without an air sleeve of some kind, in which case the plant was operating as an early and crude form of the rotary exhauster.

Dealing with the question of " surging " it was only stated in the Paper that a form of flap-valve was fitted to the outlet of the exhauster in order to prevent this condition being set up. A reference to the curves shown by Mr. Deane indicated that this condition of maximum vacuum at minimum volume was reached at vacua of about 10 inches and 16 inches Hg for the Turbos and the Millwall plant respectively. This degree of exhaustion was not obtained in practical working, as could be seen from the Table of Tests ; and, if obtained either by a continued " choke " or artificially, the form of flap-valve fitted would operate as a non-return valve and prevent the alternating positive and negative pressures in the exhaust pipe to which Mr. Willcox referred.

The failure of the gears was *not* in his (the Author's) opinion due to this cause, nor would a friction-clutch as such have obviated the trouble experienced unless arranged to *slip* at overload, and provided with a rapid and easy means for adjusting the load at which it *would* slip (different speeds and vacua being required for different grains), and for taking up the wear thereby engendered. The functions of an adjustable and variable friction clutch and a speed-increasing gear were combined in one unit in a very simple and compact form in the " Matteucci " gear previously mentioned. As the trouble experienced with the gears had been so stressed throughout the discussion, it might be permissible for him (the Author) to state briefly his own deductions as to the reasons for their failure, which were based on three years' experience in their running :—

1. When the gears were built the problem was not placed fully before the makers, chiefly from lack of previous experience as to the conditions which would be set up ;

2. The characteristic selected for the exhauster was unsuitable for the same reason ;

3. The gears were called upon to speed *up* at a 10 to 1 ratio from a reciprocating motion subject to minor cyclical irregularity, to a

* See Bibliography (page 931).

rotary motion subject to frequent variations of load and unusual overloads ; and

4. They were *at first* called upon to perform this duty through the medium of high and low speed couplings which were unsuited to the work.

They were replaced by the Wellman-Bibby couplings referred to in the Paper. These couplings ran well in themselves, had much improved the general running of the plant, and apparently overcame the shearing of the keys and keyways referred to by Mr. Willcox.